I CLAIM:

1. A liquid crystal display (LCD), comprising:

a liquid crystal cell; and

a tunable mirror, optically aligned with the liquid crystal cell, having controllable reflective and transmissive modes, such that in the reflective mode the tunable mirror primarily reflects light received from the liquid crystal cell back through the cell, and in the transmissive mode the mirror primarily transmits light towards the liquid crystal cell.

2. The LCD of claim 1, wherein the tunable mirror is a reversible electrochemical mirror (REM).

3. The LCD of claim 2, wherein the REM has a matte surface to produce a diffuse reflectance.

4. The LCD of claim 1, further comprising a backlight on a side of the tunable mirror opposite the liquid crystal cell, the backlight being controllably switchable between emissive and non-emissive states of operation, for providing backlighting the LCD in the emissive state of operation.

5. The LCD of claim 4, further comprising a first linearly polarizing element optically aligned with the

liquid crystal cell on a side opposite the tunable mirror, and having a first plane of polarization in a first linear direction.

6. The LCD of claim 5, further comprising a second linearly polarizing element optically aligned between the tunable mirror and the liquid crystal cell, having a second plane of polarization in a second linear direction which is orthogonal to said first plane of polarization.

7. The LCD of claim 6, further comprising:

a first A-plate between the first polarizing element and the liquid crystal cell; and

a second A-plate between the second polarizing element and the liquid crystal cell.

8. The LCD of claim 7, further comprising a light diffusing element optically aligned with the liquid crystal cell for producing a diffused LCD output image.

9. The LCD of claim 8, where the light diffusing element is integral with the tunable mirror, such that light is diffused upon being reflected by or transmitted through the tunable mirror.

10. The LCD of claim 4, further comprising:

a first control system for switching the tunable mirror between reflective and transmissive modes; and

a second control system for switching the backlight between emissive and non-emissive states of operation.

11. The LCD of claim 10, where the first and second controls operate in tandem, such that when the backlight is in the emissive state, the tunable mirror operates in the transmissive mode, and when the backlight is in the non-emissive state, the tunable mirror operates in the reflective mode.

12. The LCD of claim 11, wherein the first and second controls are automatically responsive to the level of ambient light, such that at a low level of ambient light the backlight operates in the emissive state and the tunable mirror operates in the transmissive mode, and at a high level of ambient light the backlight operates in the non-emissive state and the tunable mirror operates in the reflective mode.

13. The LCD of claim 12, wherein the first and second controls can be set to be either manually controllable or responsive to ambient light.

14. The LCD of claim 4 wherein:

said tunable mirror is further operable at at least one intermediate mode in which it partially reflects light received from the liquid crystal cell back through the cell, and partially transmits light received from the backlight towards the liquid crystal cell; and

said backlight is further operable at at least one intermediate state of operation in which it partially illuminates the LCD.

15. The LCD of claim 4, wherein the tunable mirror comprises:

a quarter-wave ($\lambda/4$) retarder for circularly polarizing linearly polarized light of the second linear direction to circularly polarized light of a second rotational direction, and for linearly polarizing circularly polarized light of the second rotational direction to linearly polarized light of the second linear direction, said $\lambda/4$ retarder being substantially transmissive to randomly polarized light; and

a liquid crystal reflector optically aligned with said $\lambda/4$ retarder on a side opposite the liquid crystal cell, said liquid crystal reflector being controllably switchable between transmitting and reflecting states of operation for reflecting circularly polarized light of the second rotational direction in the reflecting state, and for transmitting light in the transmitting state,

such that the tunable mirror operates in the reflective mode when the liquid crystal reflector is in the reflecting state, and in the transmissive mode when

the liquid crystal reflector is in the transmitting state.

16. The LCD of claim 4, wherein the tunable mirror element comprises:

a tunable retarder, being controllably switchable between first and second states of operation, the optical phase delay of the two states differing by $\lambda/2$; and

a reflective polarizer optically aligned with the retarder on a side opposite the liquid crystal cell, for reflecting light received from the retarder when the retarder is in the first state and for transmitting light through the retarder when the retarder is in the second state,

such that the tunable mirror operates in the reflective mode when the retarder is in the first state, and in the transmissive mode when the retarder is in the second state.

17. The LCD of claim 4, wherein the tunable mirror element comprises:

a zero to half-wave ($0-\lambda/2$) retarder, being controllably switchable between 0λ and $\lambda/2$ states of operation, for rotating the plane of polarization of linearly polarized light of the first direction to linearly polarized light of the second direction in the $\lambda/2$ state, and for transmitting light in the 0λ state; and

a reflective polarizer optically aligned with the 0-$\lambda/2$ retarder on a side opposite the liquid crystal cell, for reflecting linearly polarized light of the second direction, and for transmitting light having a linear polarization of the first direction,

such that the tunable mirror operates in the reflective mode when the 0-$\lambda/2$ retarder is in the 0λ state, and in the transmissive mode when the 0-$\lambda/2$ retarder is in the $\lambda/2$ state.

18. The LCD of claim 17, wherein the 0-$\lambda/2$ retarder is a nematic liquid crystal retarder.

20. The LCD of claim 17, further comprising a quarter-wave ($\lambda/4$) retarder between the backlight and tunable mirror.

21. The LCD of claim 17, further comprising a light diffusing element optically aligned with the liquid crystal cell for producing a diffused LCD output image.

22. The LCD of claim 4, wherein the tunable mirror comprises:

a tunable retarder, being controllably switchable between first and second states of operation, the optical phase delay of the two states differing by $\lambda/2$; and

a cholesteric reflector optically aligned with the retarder on a side opposite the liquid crystal cell, for reflecting light received from the retarder in the first state, and for transmitting light through the retarder in the second state.

such that the tunable mirror operates in the reflective mode when the retarder is in the first state, and in the transmissive mode when the retarder is in the second state.

23. The LCD of claim 22, wherein the tunable retarder is a negative quarter-wave to positive quarter-wave (+/-$\lambda/4$) retarder, controllably switchable between -$\lambda/4$ and +$\lambda/4$ states of operation,

whereby in the +$\lambda/4$ state, said retarder converts linearly polarized light of a second linear direction to circularly polarized light of a second rotational direction, and converts circularly polarized light of the second rotational direction to linearly polarized light of the second linear direction and, in the -$\lambda/4$ state, said retarder converts circularly polarized light of a first rotational direction to linearly polarized light of the second linear direction; and

whereby said cholesteric reflector reflects circularly polarized light of the second rotational direction and transmits a component of randomly polarized light having a circular polarization of the first rotational direction,

such that the tunable mirror operates in the reflective mode when the +/- $\lambda/4$ retarder is in the +$\lambda/4$

state, and in the transmissive mode when the +/- $\lambda/4$ retarder is in the $-\lambda/4$ state.

24. The LCD of claim 23, wherein the +/- $\lambda/4$ retarder comprises a quarter-wave ($\lambda/4$) retarder optically aligned with a zero to half-wave ($0-\lambda/2$) retarder.

25. The LCD of claim 23, wherein the cholesteric reflector is a diffuse reflecting cholesteric liquid crystal polymer film.

BK 9/28/00
WB 9/28/00

26. The LCD of claim 23, wherein the +/- $\lambda/4$ retarder is a ferroelectric liquid crystal retarder.

27. A tunable mirror, comprising:

a quarter-wave ($\lambda/4$) retarder for circularly polarizing linearly polarized light of a first linear direction to circularly polarized light of a first rotational direction, and for linearly polarizing circularly polarized light of the first rotational direction to linearly polarized light of the first linear direction, said $\lambda/4$ retarder being substantially transmissive to randomly polarized light; and

a liquid crystal reflector optically aligned with said $\lambda/4$ retarder, said liquid crystal reflector being

controllably switchable between reflecting and transmitting states of operation for reflecting circularly polarized light of the first rotational direction in the reflecting state, and for transmitting light in the transmitting state,

such that the tunable mirror reflects linearly polarized light of the first linear direction entering the $\lambda/4$ retarder from a side opposite the liquid crystal reflector when the liquid crystal reflector is in the reflecting state, and transmits light entering the liquid crystal reflector from a side opposite the circularly polarizing element when the liquid crystal reflector is in the transmitting state.

28. A tunable mirror comprising:

a zero to half-wave (0-$\lambda/2$) retarder, being controllably switchable between 0λ and $\lambda/2$ states of operation, for rotating the plane of polarization of linearly polarized light of a first direction to linearly polarized light of a second direction in the $\lambda/2$ state, and for transmitting light in the 0λ state; and

a reflective polarizer optically aligned with the 0-$\lambda/2$ retarder, for reflecting linearly polarized light of the second direction received from the retarder, back through the retarder, and for transmitting light having a linear polarization of the first direction towards the retarder,

such that the tunable mirror reflects linearly polarized light of the second direction received through

the $0\text{-}\lambda/2$ retarder from a side opposite the reflective polarizer when the $0\text{-}\lambda/2$ retarder is in the 0λ state, and transmits light having a linear polarization of the first direction received through the reflective polarizer from a side opposite the $0\text{-}\lambda/2$ retarder, when the $0\text{-}\lambda/2$ retarder is in the $\lambda/2$ state.

29. The tunable mirror of claim 28 wherein the $0\text{-}\lambda/2$ retarder is a nematic liquid crystal retarder.

30. A tunable mirror comprising:

a negative quarter-wave to positive quarter-wave $(+/-\lambda/4)$ retarder, being controllably switchable between $-\lambda/4$ and $+\lambda/4$ states of operation,

whereby in the $+\lambda/4$ state, said retarder circularly polarizes linearly polarized light of a first linear direction to circularly polarized light of a first rotational direction, and linearly polarizes circularly polarized light of the first rotational direction to linearly polarized light of the first linear direction, and, in the $-\lambda/4$ state, said retarder linearly polarizes circularly polarized light of a second rotational direction to linearly polarized light of the first linear direction; and

a cholesteric reflector optically aligned with the $+/-\ \lambda/4$ retarder, for reflecting circularly polarized light received from the $+/-\ \lambda/4$ retarder having a polarization of the first rotational direction, back

through the +/- $\lambda/4$ retarder, and transmitting circularly polarized light of the second rotational direction towards the +/- $\lambda/4$ retarder,

such that the tunable mirror reflects linearly polarized light of the first linear direction, received through the +/- $\lambda/4$ retarder from a side opposite the cholesteric reflector when the +/- $\lambda/4$ retarder is in the $+\lambda/4$ state, and transmits circularly polarized light of the second rotational direction received through the cholesteric reflector, on a side opposite the +/- $\lambda/4$ retarder when the +/- $\lambda/4$ retarder is in the $-\lambda/4$ state.

31. The tunable mirror of claim 30, wherein the cholesteric reflector is a diffuse reflecting cholesteric liquid crystal film.

32. The tunable mirror of claim 31, wherein the +/- $\lambda/4$ retarder comprises a 0-$\lambda/2$ retarder and a $\lambda/4$ retarder.

33. A method of operating a liquid crystal display (LCD), comprising:

primarily reflecting light entering a first side of a liquid crystal cell and exiting a second side of said liquid crystal cell back through the liquid crystal cell when the amount of light entering from the first side of

the liquid crystal cell is above a viewability threshold; and

generating and primarily transmitting a backlight emission from the second side of the liquid crystal cell through the liquid crystal cell when the amount of light entering from the first side of the liquid crystal cell falls below said viewability threshold.

34. The method of claim 33, wherein the primarily reflecting step comprises:

linearly polarizing randomly polarized light entering from the first side of the liquid crystal cell to a first direction of polarization;

selectively rotating the light thus linearly polarized to a second direction of polarization, the first and second directions of polarization being mutually orthogonal; and

selectively reflecting the light having the second direction of polarization, but not the light having the first direction of polarization, back through the liquid crystal cell.

35. The method of claim 34, wherein the selectively reflecting step comprises:

transmitting the light having the second direction of polarization, but not the light having the first direction of polarization; and

reflecting said light having the second direction of polarization back through the liquid crystal cell.

36. The method of claim 34, wherein the primarily transmitting step comprises:

polarizing the generated backlight emission to said second direction of linear polarization; and

selectively rotating the light having the second direction of linear polarization to the first direction of linear polarization.

37. The method of claim 36, further comprising transmitting the light exiting said first side of the liquid crystal cell and having the first direction of polarization, but not the second, to an LCD output.

38. The method of claim 37, further comprising:

diffusing the light transmitted through the LCD to produce a diffused LCD output image.

39. A method of operating a liquid crystal display (LCD), comprising:

primarily reflecting light entering a first side of a liquid crystal cell and exiting a second side of the liquid crystal cell back through the liquid crystal cell when the amount of light entering from the first side of the liquid crystal cell is above a viewability threshold;

generating and primarily transmitting a backlight emission from the second side of the liquid crystal cell

through the liquid crystal cell when approximately no light enters the first side of the liquid crystal cell; and

partially reflecting light entering a first side of a liquid crystal cell and exiting a second side of the liquid crystal cell back through the liquid crystal cell, and generating and partially transmitting a backlight emission from the second side of the liquid crystal cell through the liquid crystal cell when light entering from the first side of the liquid crystal cell falls below said viewability threshold, said backlight emission being generated in an amount sufficient to supplement the reflected light such that it reaches said viewability threshold.

40. A method of operating a liquid crystal display (LCD) comprising:

transmitting linearly polarized light entering a first side of a liquid crystal cell, through the liquid crystal cell, said linearly polarized light having a first direction of linear polarization;

selectively rotating while transmitting said polarized light through the liquid crystal cell to a second direction of linear polarization, said second and first directions of linear polarization being mutually orthogonal;

circularly polarizing the linearly polarized light having the second direction of linear polarization to a circular polarization of a second rotational direction; and

reflecting the circularly polarized light having the circular polarization of the second rotational direction, back through the liquid crystal cell, when the amount of light entering the first side of the liquid crystal cell is above a predetermined viewability threshold.

41. The LCD method of claim 40, further comprising transmitting the linearly polarized light having the second direction of linear polarization, and absorbing the light having the first direction of linear polarization, before circularly polarizing said linearly polarized light having the second direction of linear polarization.

42. The LCD method of claim 40, further comprising:

generating a backlight emission on a side of the liquid crystal cell opposite the first side, when the amount of light entering the first side of the liquid crystal cell is below a predetermined viewability threshold;

linearly polarizing the backlight emission to the second direction of linear polarization; and

selectively rotating while transmitting said backlight emission entering on a side of the liquid crystal cell opposite the first, and having the second direction of linear polarization, through the liquid crystal cell, to the first direction of linear polarization.

43. The LCD method of claim 42, further comprising transmitting the light exiting said first side of the liquid crystal cell and having the first direction of polarization, but not the second, to the LCD output.

44. An LCD method comprising:

transmitting linearly polarized light entering a first side of a liquid crystal cell, through the liquid crystal cell, said linearly polarized light having a first direction of linear polarization;

selectively rotating while transmitting said polarized light through the liquid crystal cell to a second direction of linear polarization, said second and first directions of linear polarization being mutually orthogonal;

transmitting said polarized light having the second direction of linear polarization, but not the first; and

reflecting said polarized light having the second direction of linear polarization back through the liquid crystal cell when the amount of light entering the first side of the liquid crystal cell is above a viewability threshold.

45. The LCD method of claim 44, further comprising:

generating a backlight emission on a side of the liquid crystal cell opposite the first side, when the amount of light entering the first side of the liquid

crystal cell is below the predetermined viewability threshold;

transmitting a component of said backlight emission having a linear polarization of the first direction;

rotating said light having the linear polarization of the first direction to the linear polarization of the second direction; and

selectively rotating said light having the linear polarization of the second direction, to a linear polarization of the first direction, while transmitting said light through the liquid crystal cell.

46. The LCD method of claim 45, further comprising transmitting the light exiting said first side of the liquid crystal cell and having the first direction of polarization, but not the second, to the LCD output.

47. The LCD method of claim 44, further comprising:

diffusing the light transmitted through the LCD to produce a diffused LCD output image.

48. An LCD method comprising:

transmitting linearly polarized light entering a first side of a liquid crystal cell, through the liquid crystal cell, said linearly polarized light having a first direction of linear polarization;

selectively rotating while transmitting said polarized light having the first direction of linear

polarization, through the liquid crystal cell, to a second direction of linear polarization, said second and first directions of linear polarization being mutually orthogonal;

circularly polarizing said light having the linear polarization of the second direction to a linear polarization of a second rotational direction when the level of light entering the first side of the liquid crystal cell is above a viewability threshold; and

reflecting said polarized light having the circular polarization of the second rotational direction towards the liquid crystal cell.

49. The LCD method of claim 48, further comprising transmitting the polarized light having the second direction of linear polarization, but not the first, after selectively rotating said polarized light having said first direction of linear polarization.

50. The LCD method of claim 49, further comprising:

linearly polarizing said reflected polarized light having the circular polarization of the second rotational direction, to a linear polarization of the second direction, after reflecting said light towards the liquid crystal cell;

selectively rotating while transmitting said linearly polarized light through the liquid crystal cell, to a linear polarization of the first direction.

51. The LCD method of claim 50, further comprising:

generating a backlight emission when the level of light entering the first side of the liquid crystal cell falls below the predetermined viewability threshold;

transmitting the component of said backlight having a circular polarization of a first rotational direction;

linearly polarizing said light to a polarization of the second direction; and

selectively rotating while transmitting said light through the liquid crystal cell to a linear polarization of the first direction.

52. The LCD method of claim 51, further comprising transmitting the light exiting said first side of the liquid crystal cell and having the first direction of polarization, but not the second, to the LCD output.

53. A display system, comprising:

an operating system and

a liquid crystal display (LCD) connected to said operating system to display a characteristic of said operating system, said LCD comprising:

a liquid crystal cell;

a tunable mirror optically aligned with the liquid crystal cell, having controllable reflective and transmissive modes,

a backlight on a side of the tunable mirror opposite the liquid crystal cell, the backlight being controllably switchable between on and off states of operation such that, in the reflective mode, the tunable mirror primarily reflects light received from the liquid crystal cell back through the cell, and in the transmissive mode the mirror primarily transmits light received from the backlight towards the liquid crystal cell; and

a first linearly polarizing element optically aligned with the liquid crystal cell on a side opposite the tunable mirror, and having a first plane of polarization in a first linear direction.

54. The display system of claim 53, further comprising a second polarizing element optically aligned between the tunable mirror and the liquid crystal cell, having a second plane of polarization in a second linear direction which is orthogonal to said first plane of polarization.

55. A method of operating a tunable mirror, comprising:

primarily reflecting light of a first polarization from the tunable mirror when it is in a reflective mode; and

primarily transmitting light of a second polarization through the tunable mirror when it is in a transmissive mode.

56. The method of claim 55, further comprising polarizing randomly polarized light to said first polarization before primarily reflecting the light.

57. The method of claim 56, wherein said first polarization is a circular polarization of a first rotational direction.

58. The method of claim 57, wherein said second polarization is random polarization.

59. The method of claim 56, wherein said first polarization is a linear polarization of a first direction.

60. The method of claim 59, further comprising polarizing randomly polarized light to said first polarization, before primarily reflecting said first polarization light.

61. The method of claim 60, further comprising polarizing randomly polarized light to said second direction, and primarily transmitting said second direction light.

62. The method of claim 61, wherein said second polarization is a linear polarization of a second direction, orthogonal to said first direction.

63. The method of claim 62, wherein said primarily transmitting step further comprises rotating by 90° after polarizing said randomly polarized light to said second direction, such that said light is rotated to the polarization of the first direction.

64. The method of claim 55, wherein the primarily transmitting step further comprises converting light of said second polarization to said first polarization.

65. The method of claim 64, wherein said first polarization is a linear polarization in a first direction.

66. The method of claim 65, wherein the primarily reflecting step comprises:

converting the light having said linear polarization of said first direction to a circular polarization of a first rotational direction;

reflecting the light having said circular polarization of said first rotational direction; and

converting the light having said circular polarization of said first rotational direction back to a linear polarization in said first direction.

67. The mirror method of claim 66, wherein said second polarization is a circular polarization of a second rotational direction.

68. The mirror method of claim 67, further comprising converting randomly polarized light to said second polarization before primarily transmitting said light.

69. The mirror method of claim 68, further comprising converting randomly polarized light to said first direction of polarization before primarily reflecting said light.